Collaboration with Williams International to Demonstrate the Characteristics of a Foam-Metal-Liner Installed Over-the-Rotor of a Turbofan Engine

A Williams International FJ44-3A 3000-lb thrust class turbofan engine was used as a demonstrator for foam-metal liner installed in close proximity to the fan. Two foam metal liner designs were tested and compared to the hardwall. Traditional Single-Degree-of-Freedom liner designs were also evaluated to provide a comparison. Normalized information on farfield acoustics is presented in this paper. The results show that up to 5 dB PWL overall attenuation was achieved in the forward quadrant. In general, the foam-metal liners performed better when the fan tip speed was below sonic.

Collaboration with Williams International to Demonstrate the Characteristics of a Foam-Metal-Liner Installed Over-the-Rotor of a Turbofan Engine.

Acoustics Technical Working Group Meeting
23-24 September-2008

Dan Sutliff (GRC) Dave Elliott (GRC) Mike Jones (LaRC)
Tom Hartley (Williams International)

Outline

Background

FJ44 / Liner

AAPL Facility / Test

Results

Discussion

Rationale

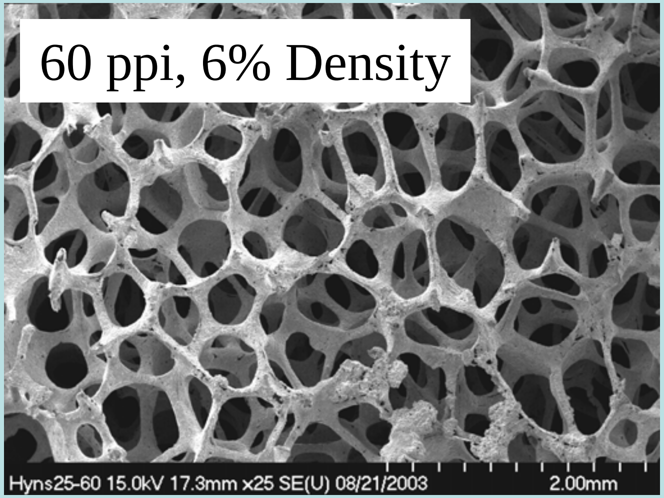
Improve upon Traditional Liners Used in Turbofan Engines by Replacing with Foam Metal Liner

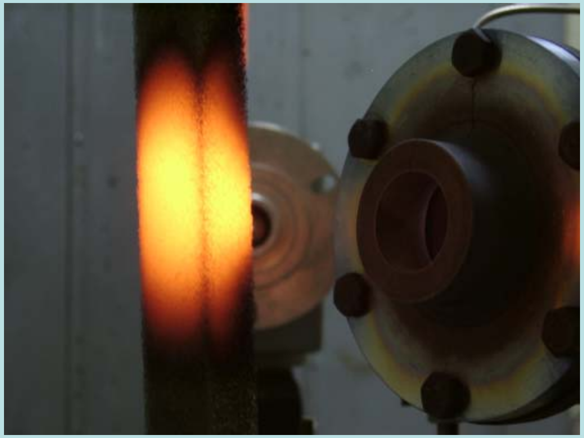
- Traditional Liners are “tuned” - Single Degree of Freedom.
  (i.e. limited Band Width)
- Limited BW and/or unique design required.
- Not suitable for adverse environments (i.e. close to /over the rotor)
  ‘distant’ from source.
- “Over the rotor” application requires rub & containment consideration.
- Ideally - would like to use a single component for improved attenuation,
  fan rub & containment.

Historical Outline

- 2003 - 2004 RTX / LaRC preliminary studies of foam metal material and acoustic characteristics
- 2005 - 2006 ANCF tests of Foam Metal Liner in lab
- April-2007: WI representatives attended Acoustics Technical Working Group meeting and expressed interest in applying foam metal liner to FJ44 engine.
- 23-May-2007: RTA/AAPL team visited WI and outlined collaboration with each parties supplying area of expertise; with less than $0-50K changing hands ($0)
  - WI:
    - to provide engine & support (ideally:turnkey!!)
    - liner fabrication
    - engine integration
  - NASA:
    - provide manpower and expertise for testing
    - expertise and data systems for acoustic testing
    - material property investigation
    - liner design guidance
- IPP seed fund awarded July 2007
- Delineated though Simplified Space Act agreement signed October 2007
- Added Hawker Beechcraft Corporation and Dr. W. Eversman to collaboration effort on April 2008

Metallic Foams





Advantages:

•Excellent acoustic absorption characteristics

•Ductile alloy with high temperature capability

•Sheet product identified as unusually high impact resistance

•Processing technology developed with Porvair (including face sheet brazing and complex shapes)

Flammability test: foam unaffected by 1000ºC/30 min in a burner rig. Long life in oxidizing environment to at least 800ºC.

Immersion tests: foam specimens with a variety of size and shapes in various fluids such as water, skydroll, advanced hydraulic fluid and jet fuel (2 hr immersion + 2 hr ambient drying). Does not readily absorb fluids.

Stress Tests : Mechanical properties surveyed, including compression, bending, tensile (w/face sheets). Can withstand expected mechanical loads.

Rub Tests : Completed

Impedance Tube Tests

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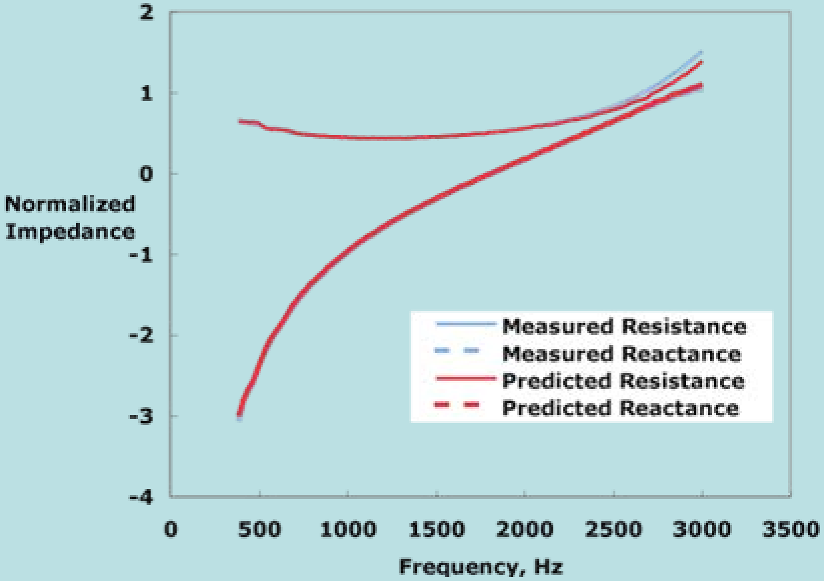
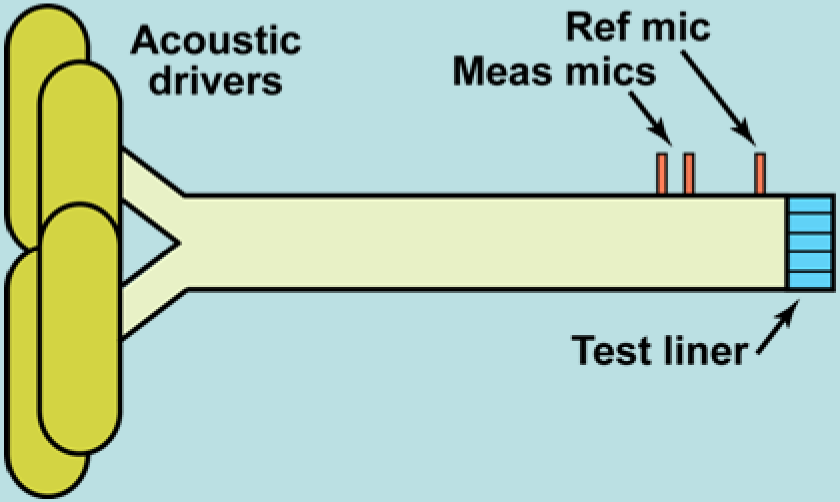
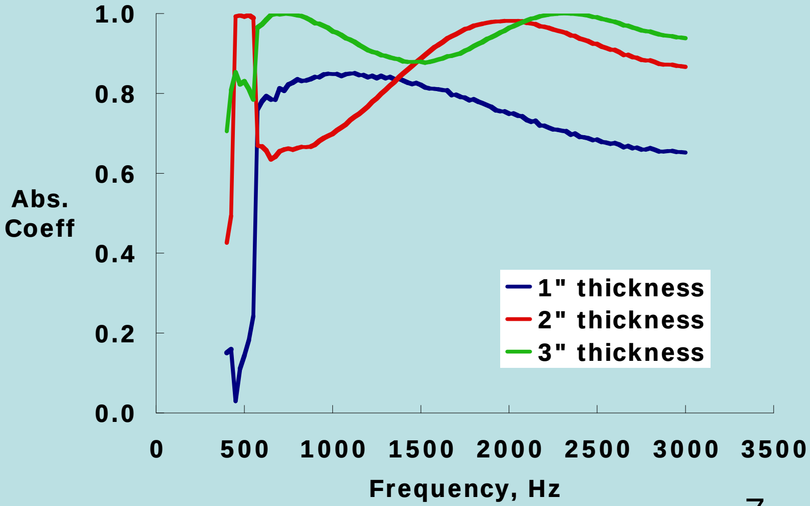
Normal Impedance Tube Tests at LaRC

- Porosities (20 -100 ppi)
- Densities (4-8%)
- (2” x 2” x 0.425”) samples
- Two-microphone procedure
- Two-thickness procedure







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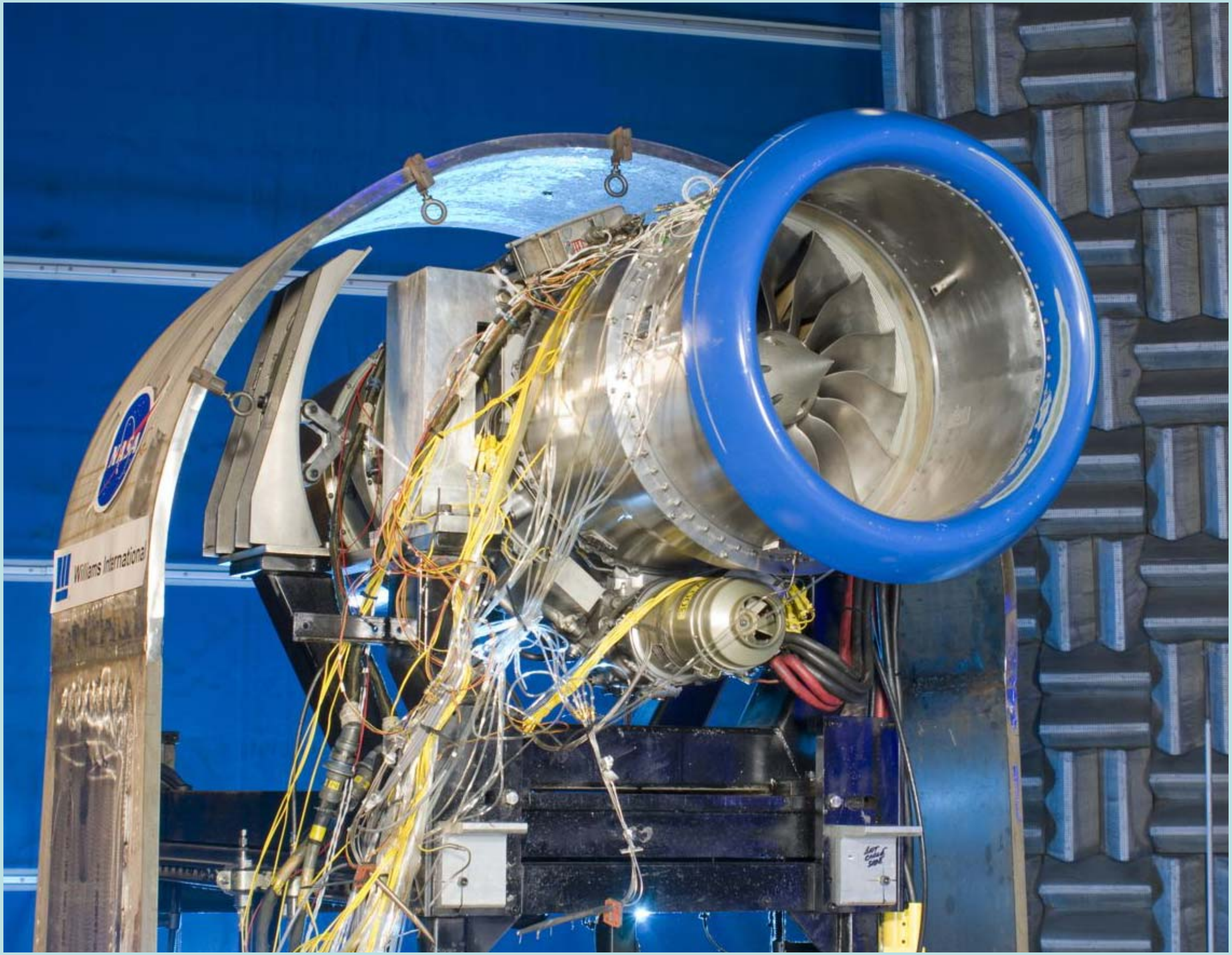
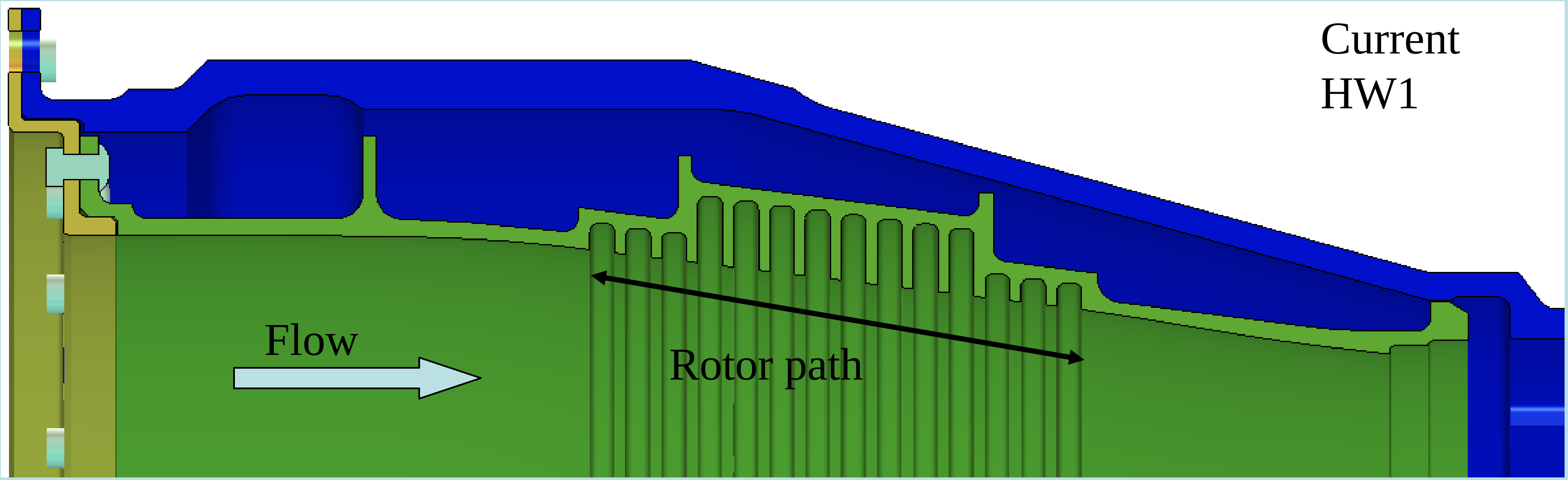
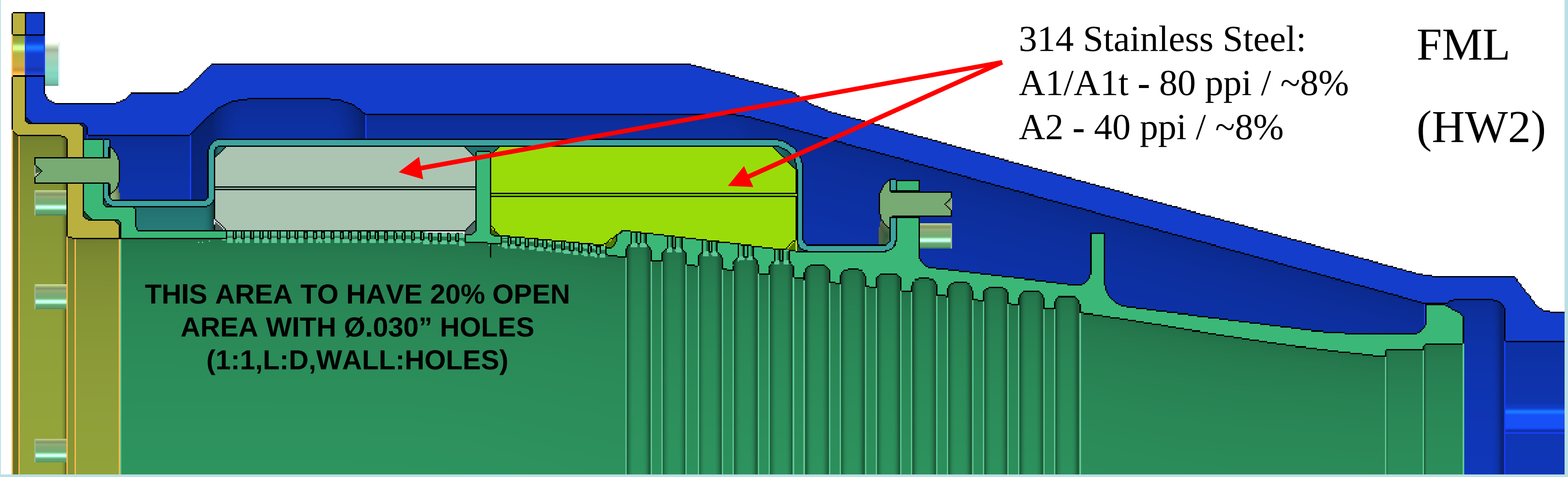
FJ-44 -3A Overview

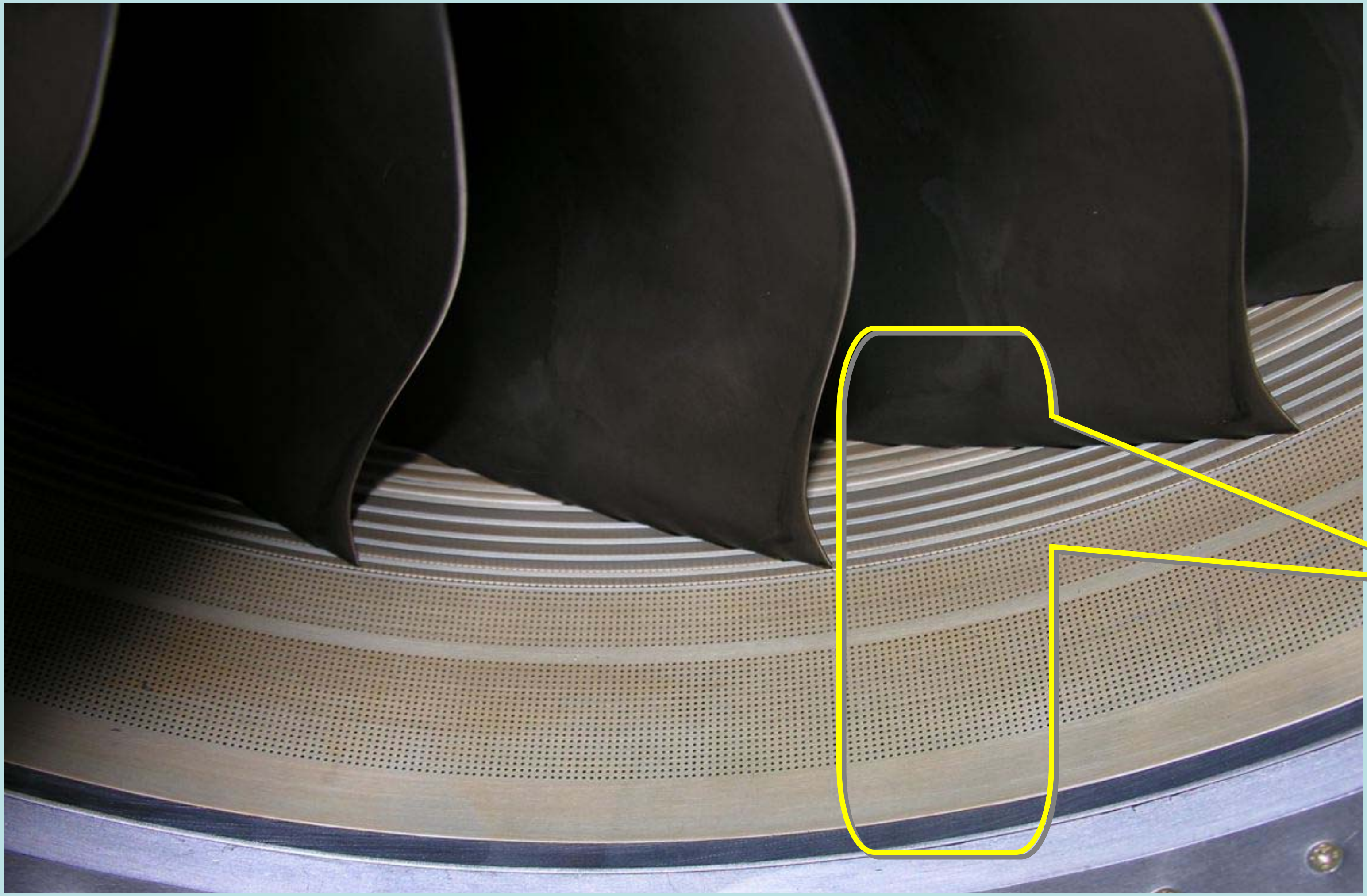


Fan Case & Insert Design





FML Close-up



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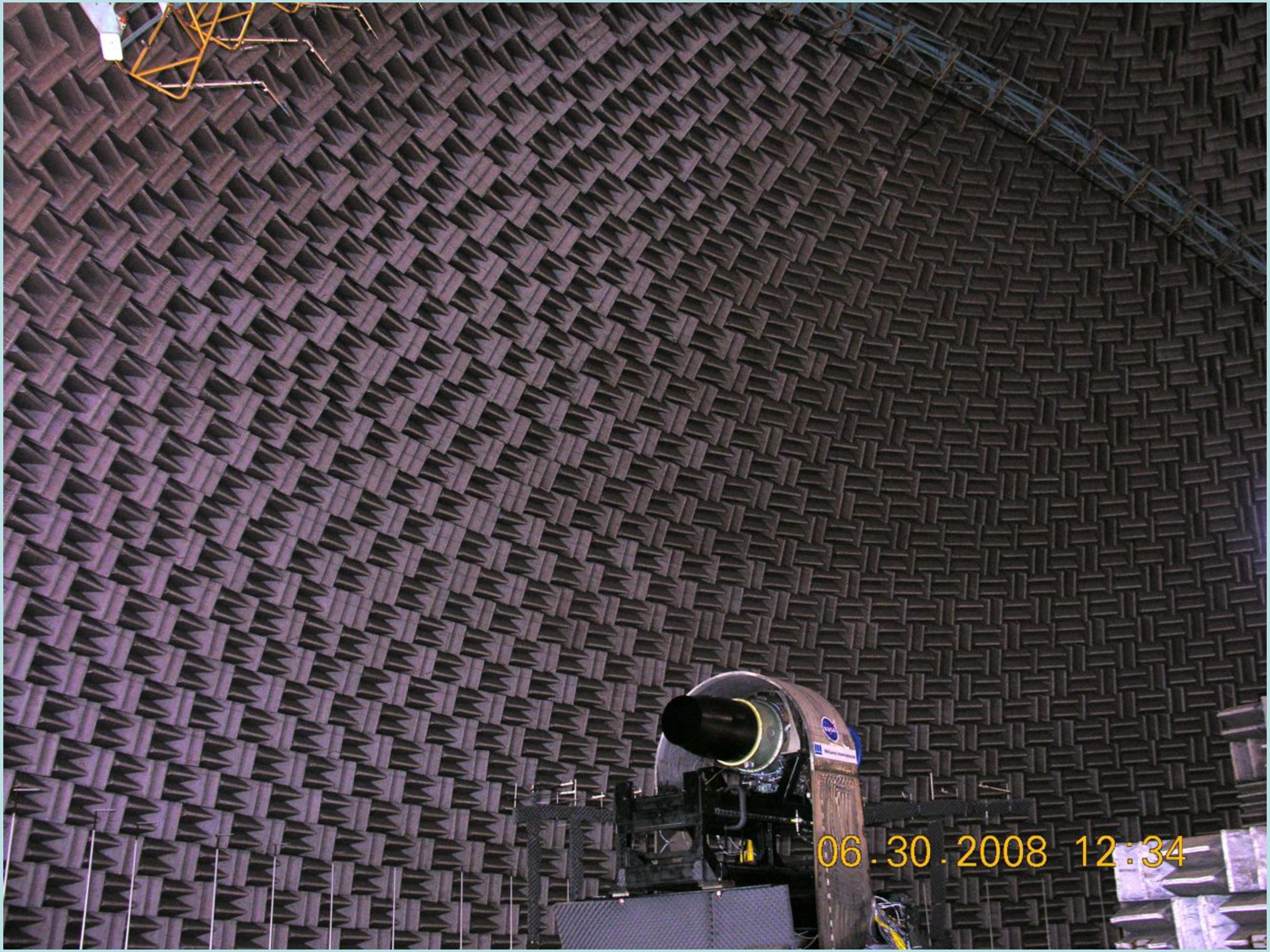
Placement in AAPL



Schedule as Tested

CONFIGURATONS TESTED:

	HW0	Hardwall configuration - original fan shroud (phased array)
	HW1	Hardwall configuration - New inlet & baseline fan shroud
new fan shroud	**HW2**	**Hardwall configuration**
new fan shroud	**A1-80**	**Fan case only treated - 80 ppi foam**
new fan shroud	**A1t-80**	**Fan case only treated - 80 ppi foam near the rotor only**
new fan shroud	**A2-40**	**Fan case only treated - 40 ppi foam**
	SDOF-71	Inlet only treated - C-71 - Hybrid thick/thin treatment zones
	SDOF-72	Inlet only treated - C-72 - Thin core treatment (new/orig fan shroud)

DATA TAKEN:

Nearfield Acoustic	**15-mic array @ 10'/10'**
Farfield Acoustic	28-mic array @ ~60' (not planar)
In-Duct Dynamic	9-high response transducer linear array in inlet
Rotating Rake Modal	14-mic radial distribution in inlet
Flow Data	**Inlet: Pt rakes ; Ps wall taps** **Bypass: Pt/Tt rake**

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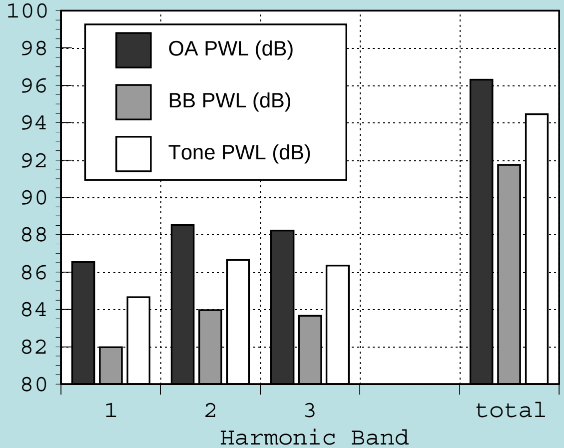
Near-Field Data Reduction

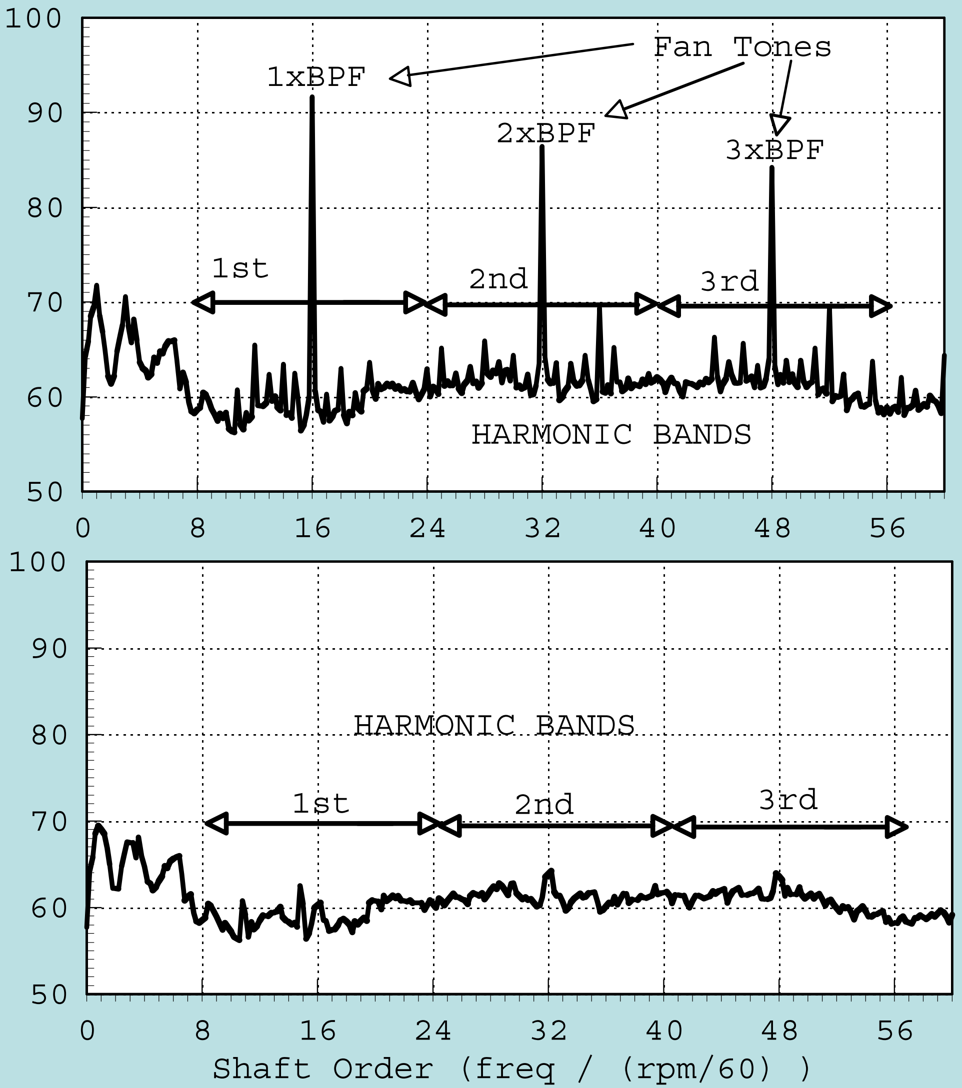
- Data acquired synchronously sampled to fan shaft @ 144/rev
- Frequency/time domain averaged
- Spectra for each microphone integrated over 'harmonic bands'

  i.e. $^1/_2$ to $1^1/_2$ harmonics

  or 8 to 24 shaft orders (etc)

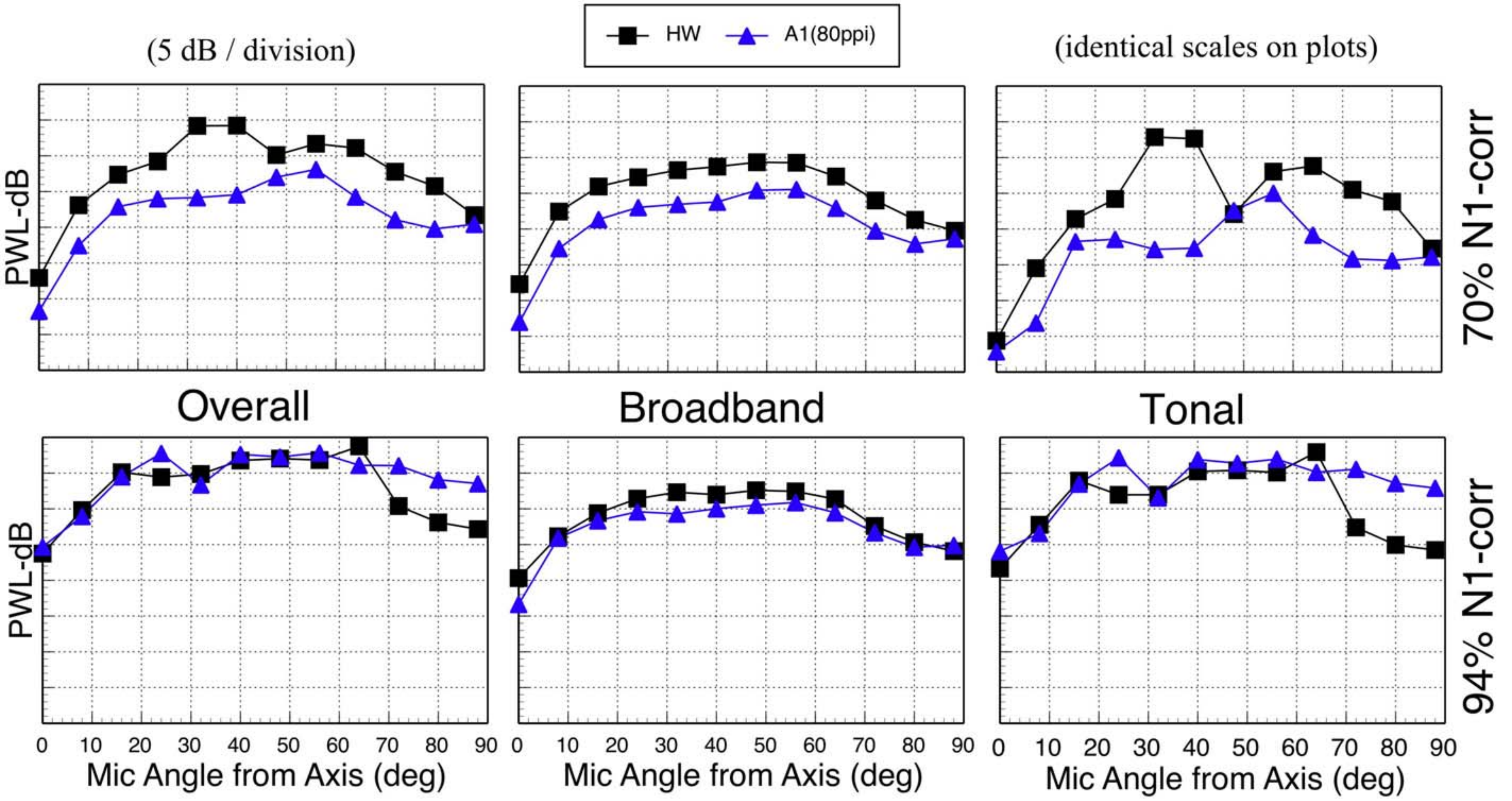
  multiplied by area, etc, to obtain PWL
- Overall/Broadband/Tones





Nearfield Directivity Plots

1st Harmonic Band / BPF



Nearfield Results (10’ inlet arc)

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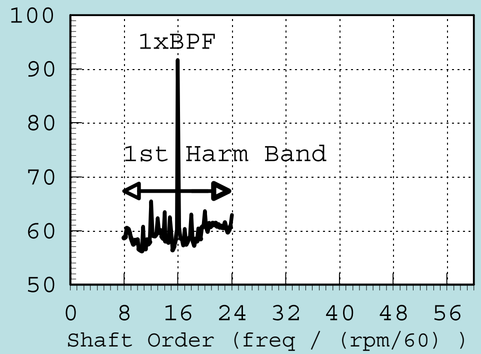
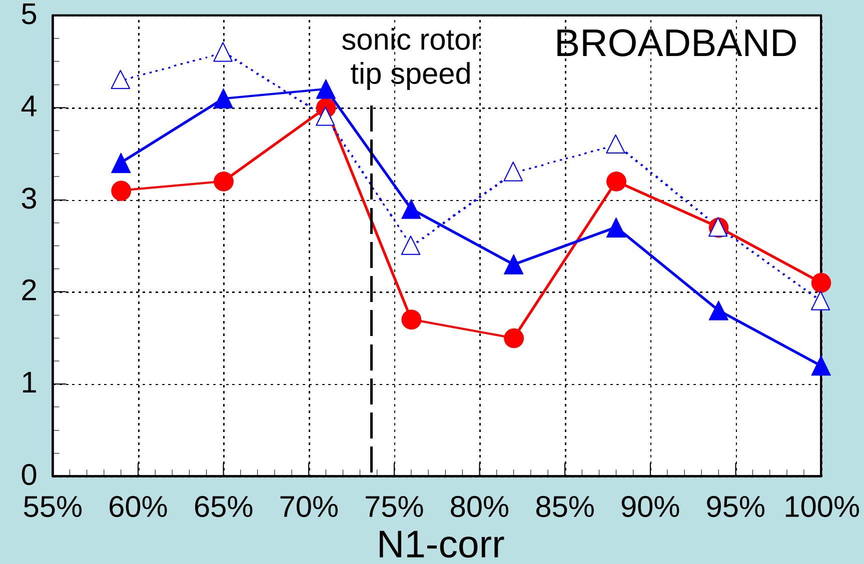
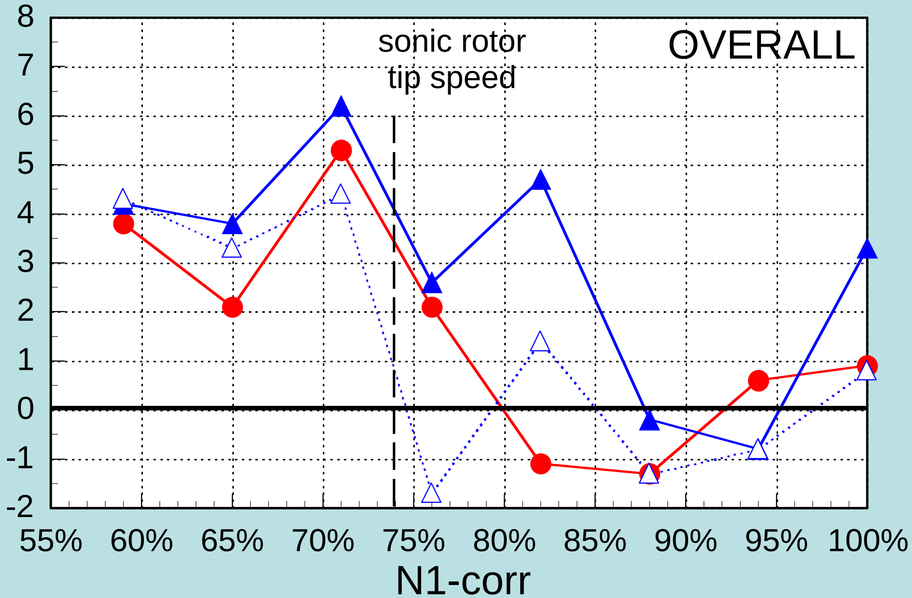
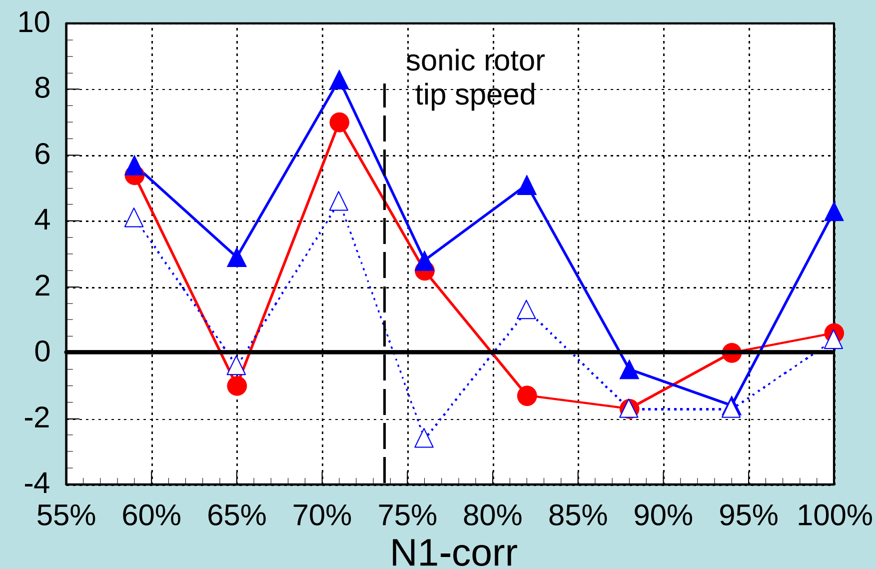




A2 (40 ppi) A1 (80 ppi) A1t





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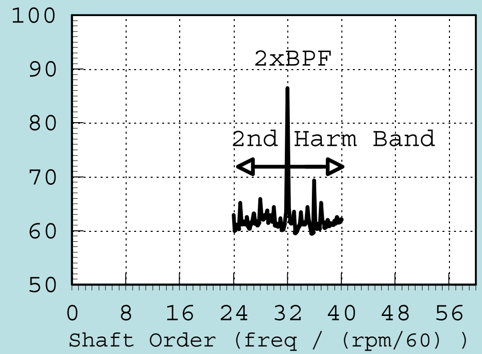
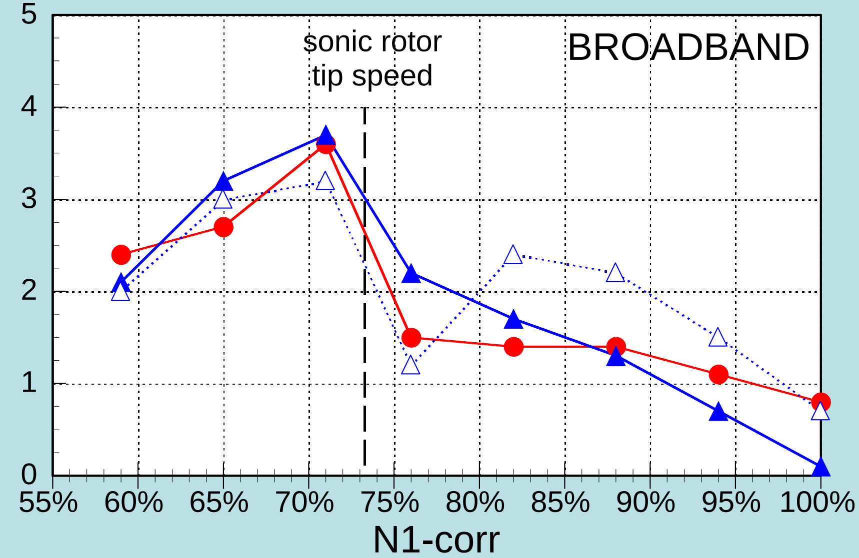
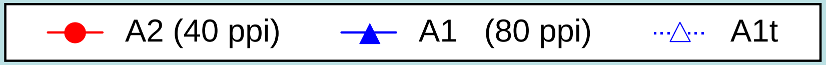
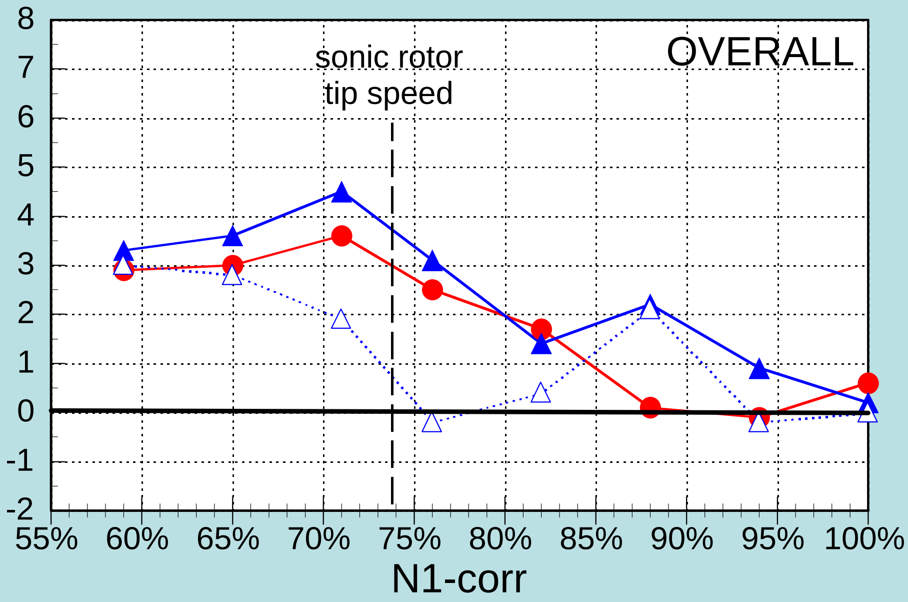
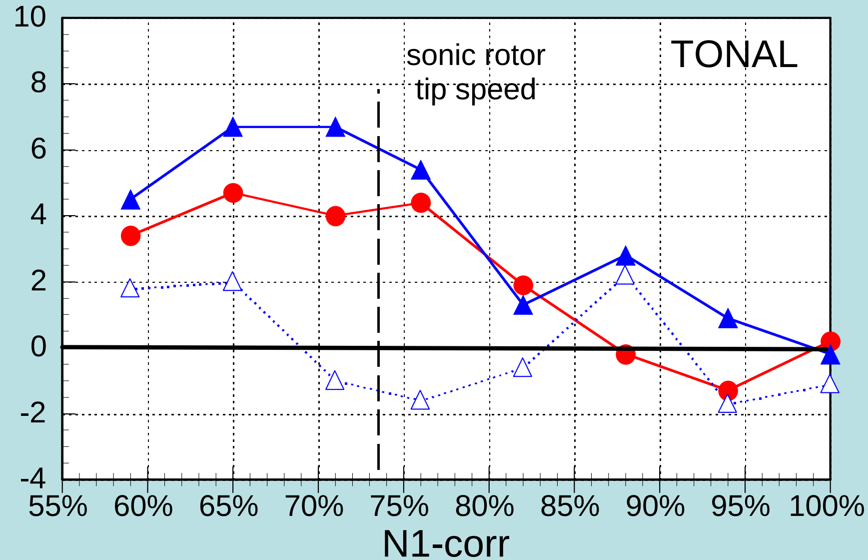


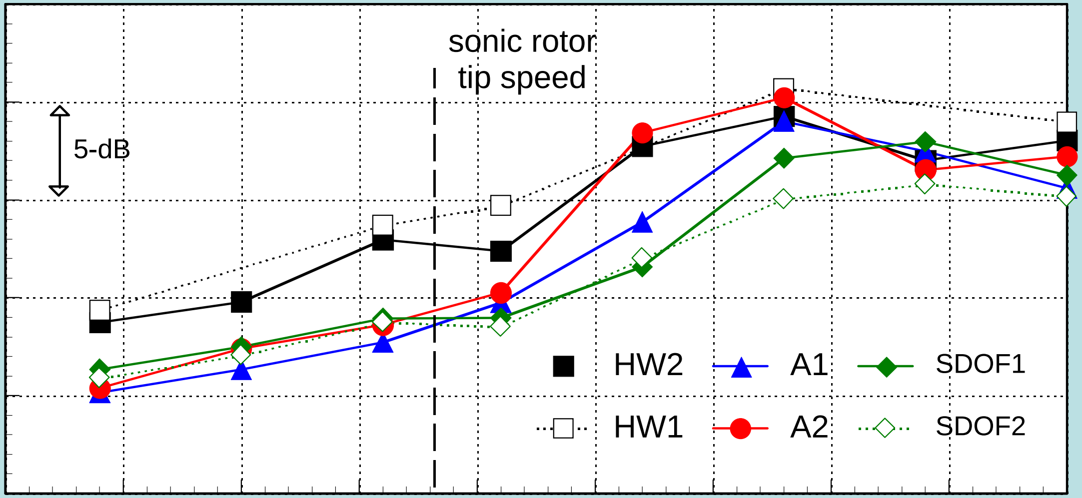


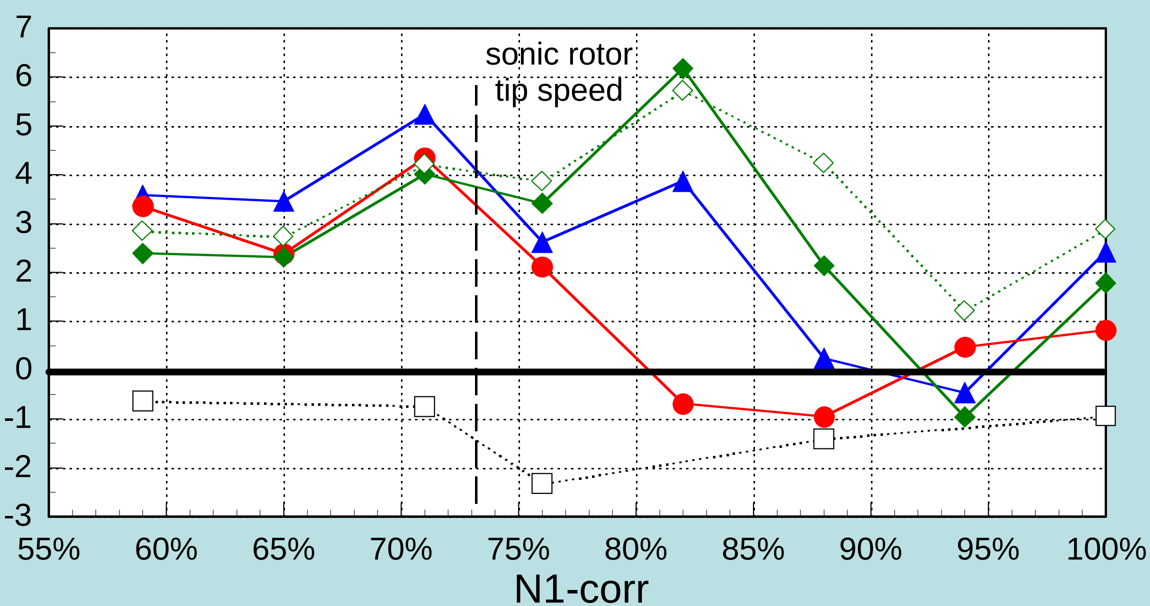






Acoustic Summary (1)





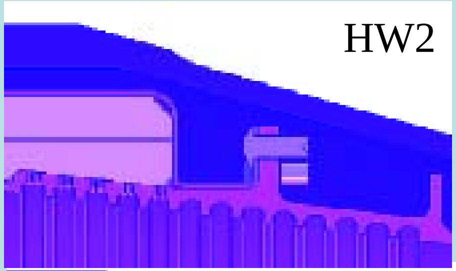
9” SDOF liner in inlet:

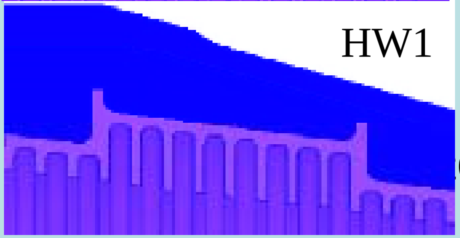
SDOF1 - thick liner (except TT1 cut-out)

•fan BPF targeted at 100% N1c

SDOF1 - thin liner

fan BPF targeted at 75% N1c





Performance (1)

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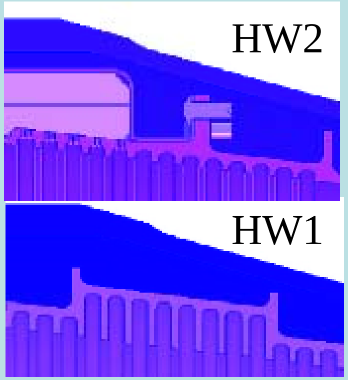
Limited instrumentation:

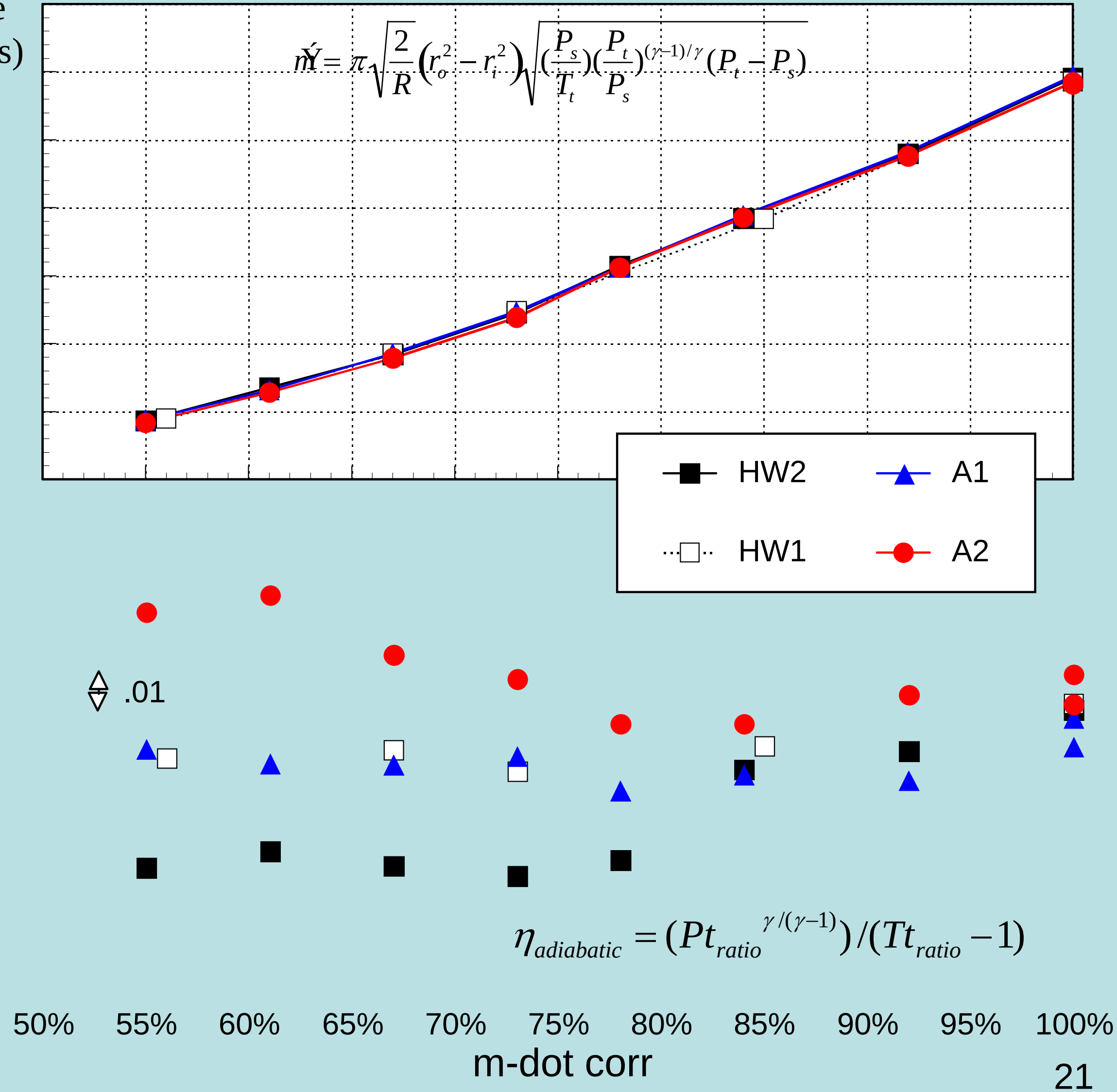
4 Pt (5 ports) rakes in inlet w/ Ps at base

3 Pt / 3Tt rakes in bypass (behind stators)

Pt / Tt-rakes	Inlet	Bypass
Row	10.322	9.450
R5	*9.769*	*8.575*
R4	*8.649*	*8.200*
R3	*7.325*	*7.872*
R2	*5.701*	*7.450*
R1	*3.368*	*7.075*
Riw	0.875	7.000



Simple flow computations:



$$\dot{m} = \pi\sqrt{\frac{2}{R}}\left(r_o^2 - r_i^2\right)\sqrt{\left(\frac{P_s}{T_t}\right)\left(\frac{P_t}{P_s}\right)^{(\gamma-1)/\gamma}(P_t - P_s)}$$

$$\eta_{adiabatic} = (Pt_{ratio}{}^{\gamma/(\gamma-1)})/(Tt_{ratio} - 1)$$

Performance (2)

WI used acquired test parameters as input to engine simulation deck to estimate performance impact of the FML on select engine performance parameters.

(#'s relative to HW2 - effect of FML)

Δ Fn	100% N1c	88% N1c	70% N1c
HW1	+3.0%	+3.5%	+5.6%
HW2	---	---	---
A2	+0.6%	+0.5%	+0.7%
A1	-1.5%	-2.2%	-2.5%

Δ S.M.	100% N1c	88% N1c	70% N1c
HW1	+2.5%	+3.9%	+4.3%
HW2	---	---	---
A2	+0.4%	+0.5%	+0.5%
A1	-0.9%	-1.3%	-1.7%

Δ SFC	100% Fn	88% Fn	70% Fn(?)
HW1	-0.4%	-1.5%	-4.6%
HW2	---	---	---
A2	+0.0%	-0.1%	-0.1%
A1	+0.2%	+0.6%	+1.2%

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Foam Metal Liner was used successfully in an high-speed turbofan engine:

- Significant attenuation achieved from 2 acoustic designs
- Performance penalty at optimum acoustic design
- No performance penalty at off- optimum acoustic design

FML attenuates tones & broadband / not shocks(?).

Aero/Acoustic design was not integrated.